Analysis of Factors Affecting Energy Consumption by Civil Buildings in China's Urban Areas

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Abstract

Civil buildings in urban areas are one of the main fields of energy consumption. The energy consumption influencing factors by civil buildings in Chinese cities between 1997 and 2007 is studied using the LMDI method, and the total increase of energy consumption is divided into four parts: urban population effect, per capita floor space effect, building structure effect and building energy intensity effect. The results show that between 1997 and 2007, growth in energy consumption by civil buildings in China's urban areas is largely driven by the increasing urban population and per capita floor space, which have contributed 56.4% and 87.6% respectively and exhibited a significant trend of increase. The structural proportion of residential buildings and public buildings are hardly an influencing factor. The reduction in the intensity of energy consumption by buildings is the major factor that deters the total growth of energy consumption, contributing -43.7%. However, this deterrence is slowing down. The key measure to suppress the growth of civil building energy consumption in urban areas is to reduce the intensity of building energy consumption.

Keywords

Building Energy Consumption; Influencing Factors; LMDI; China

Introduction

Building is the sector that consumes the second largest amount of energy, following the industry. At present, China is experiencing fast urbanization and the construction boom that it brings about. The operations of civil buildings in the cities (non-industrial buildings) consume about 22% -25% of China's total power generating capacity. As China's urbanization level and people's living standards continue to improve, theproportion of building energy consumption* will keep rising. Jiang Yi (2005a) predicted that the total amount of new buildings constructed annually in China's towns and cities would remain at 1 billion m^2/a. By 2020, an additional 10 to 15 billion square meters of construction areas for civil use will be built, leading to the increase in building energy consumption, which will become a huge pressure on China's energy supply. Since China's current energy statistical model depends on "factory method" for statistics and data release, no statistical system is available for building energy consumption. As a result, the study of building energy focused on single building. The study of changes in overall building energy, however, is more important to decide the whole energy saving direction. In this paper, four aspects, the urban population, the per capita floor area, the building structure and the intensity of building energy consumption, are discussed to analyze the factors and the extent to which they influence the growth of energy consumption by civil buildings in China's rapid urbanization process.

Research Methods and Data Sources

Research Methods

Factor decomposition is used to decompose analyze the civil building energy consumption in urban areas. Hulten (1973a) gave a detailed description of this method. At the time, people started using indexes to decompose and analyze the energy problems. Subsequent studies were generally based on the Hulten approach. As the practical problems emerged that needed solutions and theoretical research continued to develope further, some scholars improved the original method. Boyd et al (1987a, 1988a)

* Building energy consumption refers to energy consumptions for daily use and operation, including heating, air conditioning, lighting, elevators, hot water, cooking, household appliances and office equipment, but not including any energy consumption in constructing buildings or making building materials.

proposed the multiplication and addition of the Arithmetic Mean Divisia Index (AMDI), which was later standardized by Park (1992a). Ang and Liu (2000a) proposed Logarithmic Mean Divisia Index (LMDI). According to Ang (2004a) in the 1978-2003 literature reviews, LMDI is the best of all decomposition methods, as it eliminates the residual of the operating results. In this paper, LMDI is used to decompose and analyze the civil building energy consumptions in the urban areas between 1997 and 2007. The following steps show how this approach can be achieved:

Let E be the total civil building energy consumption from civil buildings in urban areas, and the following equation exists:

$$E = \sum_i E_i = \sum_i P \times \frac{S}{P} \times \frac{S_i}{S} \times \frac{E_i}{S_i} = \sum_i P \times A \times T_i \times I_i$$

(i=1,2) (1)

Where, P is the urban population; A=S/P is the per capita urban floor space, and S is the total urban floor space; $T_i=S_i/S$ is the ratio of different types of floor space in the total area, and i is the type of buildings; $I_i=E_i/S_i$ indicates the energy consumption per unit area of different types of buildings and also means the building's energy consumption intensity, and E_i is the total energy consumption by i-type buildings.

According to the LMDI approach, the total energy consumption during the initial period is E^0, and the time T is E^T. "Multiplicative decomposition" and "additive decomposition" are used to decompose the change rate of factors as follows:

$$D_{tot} = \frac{E^T}{E^0} = D_{pop} \times D_{area} \times D_{str} \times D_{\text{int}} \tag{2}$$

$$\Delta E_{tot} = E^T - E^0 = \Delta E_{pop} + \Delta E_{area} + \Delta E_{str} + \Delta E_{\text{int}} \tag{3}$$

Subscripts pop, area, str and int represents urban population effect, per capita floor area effect, building structure effect and building energy intensity effect. The LMDI computing formula is as follows:

$$D_{pop} = \exp\left(\sum_i \frac{(E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0)}{(E^T - E^0)/(\ln E^T - \ln E^0)} \ln\left(\frac{P^T}{P^0}\right)\right) \tag{4}$$

$$D_{area} = \exp\left(\sum_i \frac{(E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0)}{(E^T - E^0)/(\ln E^T - \ln E^0)} \ln\left(\frac{A^T}{A^0}\right)\right) \tag{5}$$

$$D_{str} = \exp\left(\sum_i \frac{(E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0)}{(E^T - E^0)/(\ln E^T - \ln E^0)} \ln\left(\frac{T_i^T}{T_i^0}\right)\right) \tag{6}$$

$$D_{\text{int}} = \exp\left(\sum_i \frac{(E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0)}{(E^T - E^0)/(\ln E^T - \ln E^0)} \ln\left(\frac{I_i^T}{I_i^0}\right)\right) \tag{7}$$

$$\Delta E_{pop} = \sum_i \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \ln\left(\frac{P^T}{P^0}\right) \tag{8}$$

$$\Delta E_{area} = \sum_i \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \ln\left(\frac{A^T}{A^0}\right) \tag{9}$$

$$\Delta E_{str} = \sum_i \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \ln\left(\frac{T_i^T}{T_i^0}\right) \tag{10}$$

$$\Delta E_{\text{int}} = \sum_i \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \ln\left(\frac{I_i^T}{I_i^0}\right) \tag{11}$$

It is defined such that when a $\neq$ b, L (a, b) = (a-b) / (lna-lnb), and when a = b, L (a, b) = a.

Data Sources

TABLE 1 CIVIL BUILDING ENERGY CONSUMPTION IN CHINESE CITIES 1997-2007

Year	**Urban Population (10,000)**	**Area of Residential Buildings (100 million sq.m)**	**Area of Public Buildings (100 million sq.m)**	**Residential Building Energy Consumption (10,000 tce)**	**Public Building Energy Consumption (10,000 tce)**
1997	39449	36.2	29.3	***5834.55***	***3871.11***
1998	41608	39.7	31.2	***5862.00***	***3876.70***
1999	43748	41.7	31.8	***6019.88***	***3934.34***
2000	45906	44.1	32.5	***6161.43***	***4036.25***
2001	48064	66.5	43.6	***6324.71***	***4133.83***
2002	50212	81.8	50	***6761.48***	***4513.09***
2003	52376	89.1	51.8	***7738.07***	***5296.06***
2004	54283	96.2	52.9	***8858.51***	***6270.42***
2005	56212	107.7	56.8	***9635.53***	***6863.08***
2006	57706	112.9	61.6	***10650.80***	***7544.81***
2007	59379	120	66	***11766.06***	***8265.63***

The data on population and the civil building areas in the cities come from the China Statistical Yearbook between 1998 and 2008. The civil buildings in urban areas are divided into two categories, residential buildings and public buildings. The areas of public buildings are obtained with the year-end housing area in the cities of different regions minus the residential building areas at the end of last year. The existing statistics and survey results are consulted, and building energy consumption data are obtained from the 1998-2008 China Energy Statistical Yearbook. Energy consumption by urban residential buildings refers to the total energy consumption of urban residents minus the energy consumption associated with transport that urban residents use (transport energy consumption concerns gasoline, kerosene and 95% diesel). Energy consumption by public buildings refers to tertiary industrial energy consumption minus energy consumed on transportation, storage and postal sector and 95% gasoline, 50% diesel and other oil. Data are shown in Table 1.

Results and Discussion

The factors causing the growth of civil building energy consumption in China's urban areas between 1997 and 2007 are decomposed using equations (1) to (13). Table 2 and Table 3 show the multiplier composition and additive composition of the urban population effect, urban per capita floor space effect, building structural effect and building energy consumption intensity effect that impact the growth civil building energy consumption in urban areas.

Factors Affecting Total Energy Consumption of Urban Civil Buildings

Figure 1 shows the decomposition effect of total energy consumption by urban civil buildings across China. It can be seen from Figure 1 that the total energy consumption by civil buildings in China in 2007 was increased by 103 million tons from 97 million tons in 1997 to 200 million tons in 2007, which was mainly caused by the increase of the construction area *ΔEarea* and the urban population *ΔEpop* , which are responsible for the additional 90 million tons and 58 million tons. The adjustment of building structure *ΔEint* had curbed the total energy consumption, though not very significantly. The intensity effect of the building energy consumption *ΔEint* is -45 million tons (calculated according to Table 1, building energy consumption had decreased to 0.011 tce/m^2 in 2007 from 0.015 tce/m^2 in 1997) shows that the reduction of intensity of energy consumption by buildings had brought down the civil building energy consumption in China's urban areas to offset the additional energy consumption as a result of the population growth.

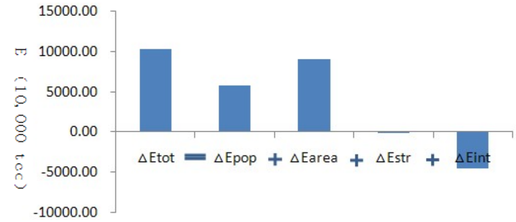

FIG. 1 ADDITIVE DECOMPOSITION OF CIVIL BUILDING ENERGY CONSUMPTION IN CHINESE CITIES IN 2007

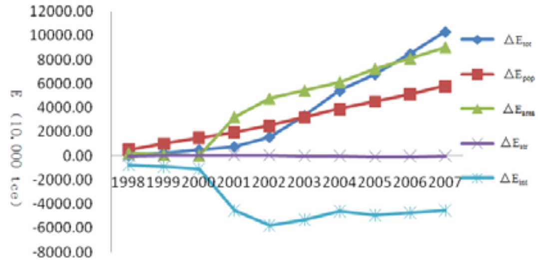

FIG. 2 DECOMPOSITION OF FACTORS AFFECTING CIVIL BUILDING ENERGY CONSUMPTION IN CHINESE CITIES BETWEEN 1997 AND 2007

The total energy consumption by civil buildings in Chinese cities grew 1.1 times over the 10 years between 1997 and 2007, with an average annual growth of 7%. Analysis based on the additive decomposition in Figure 2 shows two stages of the growing energy consumption by civil buildings in Chinese cities. The first stage is the period of 1998-2002, which shows a steady growth in building energy consumption, where urban population and per capita floor space are the main positive factors. With *ΔEpop* greater than *ΔEarea*, population growth is the main factor driving up the total building energy consumption. The second stage is the period of 2002-2005, which sees the rapid growth of the building energy consumption, where *ΔEpop* and *ΔEarea* remain the major influencing factors. The increase of per capita floor space becomes a major positive factor, indicating that the growing construction area is contributing more to the building energy consumption.

Effect of Urban Population

Between 1997 and 2007, China's urban population grew from 3.9 million to 590 million. The growing population is one of the major factors driving up energy consumption by civil building in urban areas and continues to contribute to the rising building energy consumption by adding 6 million tce per year. The contribution in 2007 amounted to 56% of the total energy increase.

Effect of Urban Per Capita Floor Space

The floor space of civil buildings in China's urban area increased 2.8 times to 18.6 billion square meters in 2007 from 6.55 billion square meters in 1997. The per capita floor area increased to 31.3 square meters from 16.6 square meters. Between 1997 and 2001, the per capita floor space had smaller impact on building energy consumption than the population growth. From 2001 onward, the impact of per capita floor space was greater than that of the urban population growth, and this trend was accelerating. The growth trend indicates that the per capita floor space is going to be the main factor that influences building energy consumption in the future.

Effect of Building Structure

Between 1997 and 2007, the ratio of residential buildings and public buildings had little impact on building energy consumption. Between 1997 and 2001, the positive effect of building structures was relatively small. Between 2001 and 2007, the effect of building structure became negative, owing to the increase in the proportion of residential buildings.

Effect of Building Energy Intensity

Between 1997 and 2007, $\Delta Eint$ remained negative, indicating that the reduced intensity of building energy consumption was the main factor that increased energy consumption by buildings. As we can be seen from Figure 2, the intensity of building energy consumption between 1997 and 2003 declined, indicating that the intensity of building energy consumption had stepped up its power to suppress the growth of civil building energy consumption in cities. Between 2003 and 2007, the intensity of building energy consumption rose, indicating the building energy consumption intensity was weakened in suppressing the growth of energy consumption by civil buildings in urban areas.

Conclusion and Recommendations

In this paper, the LMDI approach is used to decompose and analyze the energy consumption by civil buildings in China's urban areas. The results show that the growth of China's urban population and per capita floor space is the main reason for the increased energy consumption by civil buildings in the Chinese cities, contributing 56.4% and 87.6 respectively. In particular, the increase in the per capita floor space is dominating the trend, while the building structure has little impact on the total energy consumption by buildings. Meanwhile, the reduced intensity of energy consumption by buildings is the main factor that suppresses the growth of total energy consumption, contributing -43.7%. It is worth noting that the effect resulted from the reduced intensity of energy consumption is becoming weaker. By 2020, as China's level of urbanization becomes higher and the urban population and the floor area experience faster growth, there is a need to reduce the intensity of energy consumption by buildings significantly in order to have the growth of civil building energy consumption under control.

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